Relation between Ambient Air Pollution and Low Birth Weight in the Northeastern United States

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We evaluated the relation between term low birth weight (LBW) and ambient air levels of carbon monoxide (CO), particulate matter up to 10 μm in diameter (PM_{10}), and sulfur dioxide (SO_2). The study population consisted of singleton, term live births (37–44 weeks of gestation) born between 1 January 1994 and 31 December 1996 in six northeastern cities of the United States: Boston, Massachusetts; Hartford, Connecticut; Philadelphia, Pennsylvania; Pittsburgh, Pennsylvania; Springfield, Massachusetts; and Washington, DC. Birth data were obtained from National Center for Health Statistics Natality Data Sets. Infants with a birth weight < 2,500 g were classified as LBW. Air monitoring data obtained from the U.S. Environmental Protection Agency were used to estimate average trimester exposures to ambient CO, PM_{10}, and SO_2. Our results suggest that exposures to ambient CO and SO_2 increase the risk for term LBW. This risk increased by a unit increase in CO third trimester average concentration [adjusted odds ratio (AOR) 1.31; 95% confidence interval (CI) 1.06,1.62]. Infants with SO_2 second trimester exposures falling within the 25 and < 50th (AOR 1.21; CI 1.07,1.37), the 50 to < 75th (AOR 1.20; CI 1.08,1.35), and the 75 to < 95th (AOR 1.21; CI 1.03,1.43) percentiles were also at increased risk for term LBW when compared to those in the reference category (< 25th percentile). There was no indication of a positive association between prenatal exposures to PM_{10} and term LBW. Increased ambient levels of air pollution may be associated with an increased risk for LBW. *Key words:* air pollution, carbon monoxide, epidemiology, health effects, low birth weight, particulate matter, sulfur dioxide. — *Environ Health Perspect* 109(suppl 3):351–356 (2001).
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Ambient levels of sulfur dioxide (SO_2), particulate matter (PM), and carbon monoxide (CO) have been associated with an increased risk for low birth weight (LBW) (*1*–*5*). In a study conducted in China, Wang et al. (*5*) reported an association between the risk for term LBW and third trimester exposures to total suspended particles (TSPs) [adjusted odds ratio (AOR) 1.10; 95% confidence interval (CI) 1.05,1.14 for every 100 μg/m^3 increase in TSPs] and SO_2 (AOR 1.11; CI 1.06,1.16 for every 100 μg/m^3 increase in SO_2). A positive association was also observed between the risk for term LBW and exposure to CO. In a study in southern California that included potential exposure to PM up to 10 μm in diameter (PM_{10}), nitrogen dioxide, and ozone, Ritz and Yu (*3*) reported that infants with third trimester exposure levels above the 95th percentile of the CO exposure distribution (3-month average concentration > 5.5 ppm) were at an increased risk of term LBW (AOR 1.22; CI 1.03,1.44).

Dejmek conducted a study in the Czech Republic and found an association between the risk of intrauterine growth retardation and exposures to PM_{10} (AOR 1.50; CI 1.15,1.96 per every 20 μg/m^3 increase in PM_{10}) and PM up to 2.5 μm in diameter ($PM_{2.5}$) (AOR 1.34; CI 0.98,1.82 per every 20 μg/m^3 increase in $PM_{2.5}$) during the first month of pregnancy (*2*). Bobak and Leon conducted another study in the Czech Republic and examined the relation between LBW and maternal exposures to SO_2, TSPs, and nitrogen oxides (NO_x) (*1*). In this study the unit of analysis was the annual LBW experiences of the country's administrative district rather than the individual infant. A small increase in risk was observed in districts with increased exposures to SO_2 (AOR 1.10; CI 1.01,1.20 per every 50 μg/m^3 increase in SO_2), but not to other contaminants.

Rogers and colleagues examined the association between maternal exposures to ambient SO_2 and TSPs and the risk of very low birth weight (VLBW) (*4*). In this study, the exposure measure represented the combination of both TSPs and SO_2 concentrations at the birth home. A positive association between VLBW and maternal exposures above the 95th percentile of the exposure distribution of the combined contaminants was reported (AOR 2.88; CI 1.16,7.13).

Other evidence is less convincing. Bobak assessed the association of LBW with maternal exposures to SO_2, TSPs, and NO_x in each trimester of pregnancy (*6*). A small increase in the risk of LBW was observed in each trimester in relation to TSP exposures; however, the 95% CI included unity. Alderman et al. (*7*) studied the relation between LBW and ambient levels of CO during the last trimester of pregnancy. A nonsignificant increase in the risk of LBW (AOR 1.5; CI 0.7,3.5) was observed among infants exposed to CO levels equal to or greater than 3 ppm. Finally, Dolk and colleagues examined whether populations residing near cokeworks had a higher risk of LBW (*8*). Cokeworks are a major source of smoke and SO_2, and proximity to the site was used as a surrogate for exposure to these contaminants. There was no evidence of a relation between LBW and residence near cokeworks (observed/expected ratio 1.00; CI 0.95,1.06).

The biologic mechanism by which these contaminants cause growth retardation has not been established. Studies on the effects of smoking habits during pregnancy support the association of LBW with ambient levels of CO (*9*,*10*) and ambient particles (*11*). The increase in maternal carboxyhemoglobin levels associated with maternal smoking is the biologic mechanism believed to explain the relation between CO and LBW (*10*). Another hypothesis is that exposure to the polycyclic aromatic hydrocarbons (PAHs) adsorbed to air particles may influence fetal growth (*12*).

In this report we present an assessment of the relation between term LBW and maternal exposures to CO, PM_{10}, and SO_2 among residents of selected northeastern cities of the United States.

Methods

Study Population

The study population consisted of singleton, term live births between 1 January 1994 and 31 December 1996 in six cities of the Northeastern United States that had large populations (> 100,000) and routinely collected data on the study pollutants: Boston, Massachusetts; Hartford, Connecticut; Philadelphia, Pennsylvania; Pittsburgh,

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Pennsylvania; Springfield, Massachusetts; and Washington, DC. We identified study infants from birth certificates retrieved from the National Center for Health Statistics (NCHS) Natality Data Sets for 1994, 1995, and 1996.

Health Outcomes

Term LBW was defined as having a gestational age between 37 and 44 weeks and a birth weight under 2,500 g. Birth certificate data on date of mother's last menstrual period (LMP) and birth weight were used to define term LBW. We excluded infants whose birth certificate had no information on birth weight or date of mother's LMP.

Exposure Assessment

For each infant we estimated the period comprising the first, second, and third trimester from the LMP date reported on the birth certificate and assessed exposures to ambient air pollutants that might have occurred during this period. For the study period and areas, we obtained hourly monitor readings of CO and SO_2 for each day and 24-hr monitor readings of PM_{10} for every 6th day from the U.S. Environmental Protection Agency, excluding data from air monitors located in industrial areas. There were two monitors measuring CO ambient levels in Hartford and Springfield, three in Philadelphia, Pittsburgh, and Washington, and four in Boston. There was one monitor measuring ambient SO_2 levels in Boston and Hartford, two in Philadelphia and Springfield, three in Washington, and four in Pittsburgh. There were three monitors measuring PM_{10} in Hartford, Springfield, and Washington, and four monitors in the remaining cities.

We transformed SO_2 data into parts per million. We then used the monitoring data to estimate daily average ambient levels of CO and SO_2 for each of the study areas. PM_{10} readings were taken every 6th day; thus, this contaminant's trimester averages do not represent every day of the trimester as the other contaminants do. Within-cities PM_{10} readings were usually taken on the same day. Some of the daily ambient levels were estimated on the basis of one reading, but the percentage of such daily values is relatively small, it ranged from 1.6 to 28.7% in the study areas. As the daily estimates are averaged to calculate the trimester's exposure, we don't expect the daily values based on one measure to bias our exposure estimates.

On the basis of the maternal residence information registered on the birth certificate and the corresponding air pollution concentrations in the city of maternal residence, we estimated the average exposure during each trimester individually for each study subject. These estimates were based on the assumption that the city of maternal residence reported on the birth certificate was the one where the mother lived throughout the entire trimester. We excluded infants for whom ambient air data were available for less than 75% of the days.

Covariates

From the NCHS data sets, we obtained information on the following covariates: gestational age, gender, birth order, maternal age, race or ethnicity, years of education, marital status, adequacy of prenatal care, previous induced or spontaneous abortions, weight gain during pregnancy, maternal prenatal smoking, and alcohol consumption. Adequacy of prenatal care was determined on the basis of the month when prenatal care began, number of prenatal visits, and gestational age (*13*). We excluded infants whose birth certificates had no information on the study covariates.

Statistical Methods

We estimated the prevalence (%) of LBW and its 95% CI based on the binomial distribution. We carried out bivariate analyses of the relations between the outcome and exposures of interest using the odds ratio (OR) as a measure of effect. Logistic regression models were used to estimate AORs and 95% CI for term LBW, and linear regression models were constructed to assess reductions in birth weight (in grams) in relation to each air pollutant.

In constructing the models, the covariates whose inclusion in the model changed the effect of the exposure variables more than 10% were kept in the model. Then, from the full model, we excluded those variables whose deletion did not change the effect more than 10% (*14*). Covariates were entered as indicator, dichotomous, ordinal, or continuous variables in the models. Maternal age and race and season of the year were entered as indicator variables. Smoking and alcohol use during pregnancy were entered as dichotomous variables (yes, no), as well as being firstborn (yes, no), gender (male, female), marital status (married, unmarried), and previous terminations (yes, no). Prenatal care was entered as an ordinal variable (adequate, intermediate, inadequate, unknown) and weight gain and gestational age (weeks) as continuous variables.

The exposure parameter was applied in both continuous and categorical forms. The exposure variables were categorized into percentiles of the exposure distribution: < 25th, 25 to < 50th, 50 to < 75th, 75 to < 95th, ≥ 95th. The range of values for the exposure categories (to three decimals) were the following: CO: first trimester (< 0.939, 0.939–1.084, 1.085–1.237, 1.238–1.474, ≥ 1.475), second trimester (< 0.938, 0.938–1.084, 1.085–1.235, 1.236–1.470, ≥ 1.471), and third trimester (< 0.926, 0.926–1.060, 1.061–1.228, 1.229–1.457, ≥ 1.458); PM_{10}: first trimester (< 24.821, 24.821–30.996, 30.997–36.142, 36.143–46.547, ≥ 46.548), second trimester (< 24.702, 24.702–30.294, 30.295–35.410, 35.411–43.928, ≥ 43.929), and third trimester (< 24.702, 24.702–30.162, 30.163–35.642, 35.643–43.588, ≥ 43.589); SO_2: first trimester (< 7.090, 7.090–8.906, 8.907–11.969, 11.970–18.447, ≥ 18.448), second trimester (< 6.596, 6.596–8.896, 8.897–11.959, 11.960–18.275, ≥ 18.276), and third trimester (< 5.810, 5.810–8.453, 8.454–11.777, 11.778–18.134, ≥ 18.135). For the categorical analysis the group of infants with exposures under the 25th was used as the reference category. The analysis for continuous exposure parameters was conducted on the basis of a 1-unit increase in CO average trimester concentrations and a 10-unit increase in PM_{10} and SO_2 average trimester concentrations.

The multivariate analysis was performed using the STATA statistical package. In our study, the observations are independent across study areas but they may not be independent within study areas. For this reason we applied multistage regression models, which adjusted for the standard errors for clustering regarding the study area (*15*). Finally, individual models were constructed for each trimester. The presence of correlation between the exposure measures of each contaminant for the three trimesters increased the standard errors of many of the exposure variables when data for all the trimesters were included in one model.

Results

From 1994 to 1996, we identified 130,465 live births among residents of the study area. We excluded infants who were multiple births (1,905; 1.5%), those whose birth certificates had no information on date of LMP or birth weight (21,001; 17.1%), those for whom ambient air data were missing (6,406; 4.9%), and those with missing data on any covariate (11,596; 8.9%), leaving a total of 89,557 (68.6%) infants for analysis.

The prevalence of LBW tended to be higher among infants whose mothers were younger than 20 years of age or older than 35 years, nonwhite, unmarried, had a lower level of formal education, had inadequate prenatal care, low weight gain during pregnancy, and consumed alcohol or smoked during the pregnancy (Table 1). The prevalence of LBW was also higher among female than among male infants and tended to be higher among infants born in the fall or winter months.

We observed an increase in the risk for term LBW with exposures to ambient concentrations of CO, as indicated by the risk estimate for the continuous third

trimester exposure variable (AOR 1.31; CI 1.06,1.62 per every 1-ppm increase in CO) (Table 2). The risk estimates for the third trimester categorical exposure assessment were suggestive of an increase in risk in relation to CO exposure, although the risk estimates did not increase consistently. The data do not suggest an effect of CO on other trimesters.

There were no associations between exposure to ambient concentrations of PM_{10} and term LBW (Table 2). On the other hand, second trimester exposures to SO_2 were associated with an increased risk for term LBW. Infants with SO_2 exposure measures falling between the 25 and < 50th (AOR 1.18; CI 1.12,1.25), the 50 to < 75th (AOR 1.12; CI 1.07,1.17), and the 75 to < 95th (AOR 1.13; CI 1.05,1.22) percentiles were at increased risk for term LBW. No increase in risk was seen for the group with SO_2 exposure estimates falling on the highest exposure category nor for the continuous exposure variable.

Analysis stratified by race/ethnicity revealed that the association between CO and term LBW was more consistent and stronger for African–American infants (Table 3). Third trimester exposures to CO were associated with an increased risk for term LBW among infants with exposures greater than or equal to the 95th percentile of the exposure distribution (AOR 1.28; CI 1.03,1.59). First and second trimester exposures also seemed to be associated with an increased risk for term LBW among African Americans, but the associations were weaker and less precise. When CO was fitted in the model as a continuous variable, significant increases in risk were observed in relation to first (AOR 1.43; CI 1.18,1.74 per every 1-ppm increase in CO) and third trimester exposures (AOR 1.75; CI 1.50,2.04 per every 1-ppm increase in CO). A nonsignificant increase in the risk of term LBW was observed for second trimester exposures (AOR 1.27; CI 0.87,1.86 per every 1-ppm increase in CO). Third trimester exposures to CO were also associated with an increased risk for term LBW among the group of Hispanics with CO exposures falling within the 25 and <50th percentile of the exposure distribution (AOR 1.30; CI 1.22,1.38); however, a consistent exposure–response pattern between CO levels and the risk of LBW was not present.

First trimester exposures to ambient levels of PM_{10} were associated with an increased risk for term LBW among Hispanics (AOR 1.36; CI 1.06,1.75) (Table 3). However, there were no associations between exposures to PM_{10} in any trimester and term LBW among white or African–American infants.

Exposures to ambient levels of SO_2 were associated with term LBW among whites and African Americans (Table 3). Among whites, term LBW was associated with second trimester exposure estimates falling within the 50 to < 75th (AOR 1.16; CI 1.11,1.22) and the 75 to < 95th (AOR 1.30; CI 1.20,1.42) percentiles of the exposure distribution. When SO_2 was fitted in the models as a continuous variable, significant increases in risk for term LBW were observed in relation to 10-ppm increments in ambient levels of SO_2 in the first (AOR 1.18; CI 1.12,1.23), second (AOR 1.18; CI 1.02,1.35), and third (AOR 1.20; CI 1.06,1.36) trimester. Among African Americans, exposures to SO_2 during the first and second trimester also were associated with an increased risk for term LBW. Associations with term LBW were evident for first trimester exposure estimates falling within the 50 to < 75th (AOR 1.10; CI 1.00,1.20) percentile, and for second trimester exposures falling within the 25 to < 50th (AOR 1.22; CI 1.14,1.25) and the 50 to < 75th (AOR 1.07; CI 1.04,1.11) percentile. Among Hispanics there were associations between term LBW and some first and second trimester exposures to SO_2, but these were not statistically significant.

Linear regression analyses showed that the magnitude of the birth weight reductions in relation to air pollutants was quite small (data not shown). For example, in African–American infants, a 1-ppm increase in first trimester exposures to CO was associated with a mean reduction in birth weight of –45.0 g (CI –131.0,40.9), while second and

Table 1. Prevalence of low birth weight according to various maternal and infant characteristics in selected cities in the Northeastern United States, 1994–1996.

Characteristic	Total no. term births	Total no. of LBW	Low birth weight (%)	95% confidence intervals
Maternal age (years)				
< 20	15,888	728	4.6	4.3, 4.9
20–24	25,153	902	3.6	3.4, 3.8
25–29	26,460	923	3.5	3.3, 3.7
30–34	21,683	718	3.3	3.1, 3.5
≥ 35	11,969	462	3.9	3.6, 4.3
Maternal race				
Hispanic	13,117	425	3.2	2.9, 3.5
White	36,466	735	2.0	1.9, 2.1
Black	46,575	2,413	5.2	5.0, 5.4
Other	4,606	143	3.1	2.6, 3.6
Marital status				
Married	45,142	955	2.1	2.0, 2.2
Unmarried	56,011	2,778	5.0	4.8, 5.2
Maternal education (years)				
0–8	4,282	196	4.6	4.0, 5.2
9–11	19,730	1,068	5.4	5.1, 5.7
12	36,354	1,420	3.9	3.7, 4.1
13–15	19,024	547	2.9	2.7, 3.1
16+	18,106	303	1.7	1.5, 1.9
Gender				
Male	51,329	1,486	2.9	2.8, 3.1
Female	49,824	2,247	4.5	4.3, 4.7
Live birth order				
Firstborn	58,676	2,145	3.7	3.6, 3.9
Other	42,070	1,571	3.7	3.5, 3.9
Adequacy of prenatal care				
Adequate	64,036	1,736	2.7	2.6, 2.8
Intermediate	23,840	1,054	4.4	4.1, 4.7
Inadequate	8,537	668	7.8	7.2, 8.4
Alcohol use during pregnancy				
Yes	3,277	318	9.7	8.7, 10.7
No	97,876	3,415	3.5	3.4, 3.6
Weight gain during pregnancy (pounds)				
< 20	16,592	1,604	6.4	9.2, 10.1
21–30	32,426	1,126	3.3	3.3, 3.7
31–40	23,393	676	2.2	2.7, 3.1
41 or more	20,705	375	2.9	1.6, 2.0
Cigarette smoking during pregnancy				
Yes	14,641	1,112	7.6	7.2, 8.0
No	85,544	2,590	3.0	2.9, 3.1
Season				
Spring	24,631	878	3.6	3.4, 3.8
Summer	27,470	968	3.5	3.3, 3.7
Fall	24,735	943	3.8	3.6, 4.0
Winter	24,317	944	3.9	3.7, 4.1

third trimester exposures were associated with mean reductions in birth weight of –22.7 (CI –93.2,47.70) and –30.9 g (CI –63.3,1.84), respectively. Among whites a 10-ppm increase in first trimester exposure to SO_2 was associated with a mean birth weight reduction of –28.5 g (CI –61.1,4.1). Mean birth weight reductions of –21.5 (CI –59.2,16.2) and –21.3 (CI –60.3,17.7) were seen for second and third trimester SO_2 exposures, respectively.

Discussion

This study of singleton term infants in six northeastern cities of the United States provided evidence of an increased risk for term LBW in relation to increased ambient air levels of CO and SO_2, but no evidence of an association of term LBW with ambient levels of PM_{10}. Concentrations of the studied pollutants were well below the established standards.

We excluded 31.4% of the live births from the study population because of multiple births; missing information on birth weight, date of LMP, or the study covariates; or insufficient air pollution data. Infants whose birth certificates lacked information on date of LMP and birth weight were reported to differ from infants with complete information with respect to some potential determinants of LBW (*16*). We found this to be the case in our study. Infants with missing information on the date of birth and birth weight (i.e., excluded from the study population) were more likely to have been born to mothers with factors associated with an increased risk for LBW: under 20 years of age, African American, unmarried, and a lower educational level compared with infants with complete information. The effect of such exclusions would have been to decrease the overall prevalence of term LBW among the infants evaluated compared to the total population of live births in the study area, and if the exclusions were more likely to happen among

Table 2. Odds ratios and 95% confidence intervals for term low birth weight by study pollutant and trimester of gestation, 1994–1996.

	1st trimester		2nd trimester		3rd trimester	
	Crude	Adjusted[a]	Crude	Adjusted[a]	Crude	Adjusted[a]
CO						
< 25th	1.00	1.00	1.00	1.00	1.00	1.00
25 to < 50th	0.95 (0.77,1.17)	0.92 (0.79,1.08)	1.01 (0.73,1.40)	0.95 (0.81,1.11)	0.98 (0.76,1.27)	0.98 (0.83,1.14)
50 to < 75th	1.04 (0.81,1.32)	0.96 (0.78,1.16)	1.00 (0.85,1.18)	0.92 (0.77,1.09)	1.11 (0.88,1.41)	1.10 (1.00,1.21)
75 to < 95th	1.09 (0.83,1.44)	0.97 (0.86,1.18)	1.02 (0.88,1.17)	0.92 (0.78,1.09)	1.11 (0.86,1.44)	1.04 (0.89,1.22)
≥ 95th	1.41 (1.32.1.50)	0.99 (0.83,1.18)	1.57 (1.38,1.80)	1.10 (0.81,1.49)	1.59 (1.44, 1.76)	1.15 (0.94,1.42)
Continuous (1 ppm)	1.49 (0.89,2.49)	1.08 (0.91,1.28)	1.42 (0.98,2.04)	1.14 (0.83,1.58)	1.69 (0.97,2.96)	1.31 (1.06,1.62)
PM_{10}						
< 25th	1.00	1.00	1.00	1.00	1.00	1.00
25 to < 50th	1.02 (0.90,1.14)	1.02 (0.94,1.11)	1.01 (0.93,1.10)	1.06 (0.97,1.15)	0.94 (0.85,1.05)	0.98 (0.87,1.10)
50 to < 75th	0.90 (0.65,1.24)	0.90 (0.78,1.03)	0.90 (0.66,1.21)	0.95 (0.85,1.07)	0.86 (0.58,1.25)	0.92 (0.76,1.11)
75 to < 95th	0.87 (0.58,1.30)	0.85 (0.73,1.00)	0.92 (0.62,1.34)	0.91 (0.79,1.05)	0.86 (0.57,1.29)	0.88 (0.75,1.04)
≥ 95th	0.89 (0.60,1.33)	0.83 (0.70,0.97)	0.90 (0.61,1.33)	0.77 (0.63,0.95)	0.92 (0.61,1.38)	0.91 (0.77,1.07)
Continuous (10 μg/m^3)	0.93 (0.77,1.13)	0.93 (0.85,1.00)	0.95 (0.78,1.16)	0.93 (0.85,1.02)	0.95 (0.75,1.20)	0.96 (0.88,1.06)
SO_2						
< 25th	1.00	1.00	1.00	1.00	1.00	1.00
25 to < 50th	1.09 (0.82,1.46)	1.04 (0.88,1.23)	1.23 (1.00,1.51)	1.18 (1.12,1.25)	1.17 (0.90,1.53)	1.04 (0.92,1.18)
50 to < 75th	1.10 (0.91,1.33)	1.04 (0.94,1.15)	1.09 (0.99,1.21)	1.12 (1.07,1.17)	1.11 (0.90,1.36)	1.02 (0.87,1.18)
75 to < 95th	0.96 (0.84,1.09)	0.98 (0.81,1.17)	1.05 (0.92,1.19)	1.13 (1.05,1.22)	1.02 (0.91,1.15)	1.04 (0.84,1.28)
≥ 95th	0.87 (0.68,1.11)	0.88 (0.73,1.07)	0.76 (0.66,0.89)	0.87 (0.80,0.95)	1.03 (0.83,1.27)	1.06 (0.76,1.47)
Continuous (10 ppm)	0.95 (0.84,1.08)	0.98 (0.93,1.03)	0.93 (0.80,1.09)	1.01 (0.93,1.10)	0.99 (0.84,1.16)	1.01 (0.86,1.20)

[a]Alcohol consumption, smoking during pregnancy, maternal education, maternal age, maternal race/ethnicity, marital status, weight gain during pregnancy, previous terminations, gender of infant, season of birth, firstborn, prenatal care, gestational age, and other pollutants.

Table 3. Adjusted odds ratios and 95% confidence intervals for term low birth weight by study pollutant, trimester of gestation, and race/ethnicity, 1994–1996.

	Whites			African Americans			Hispanics		
	1st trimester	2nd trimester	3rd trimester	1st trimester	2nd trimester	3rd trimester	1st trimester	2nd trimester	3rd trimester
CO									
< 25th	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
25 to < 50th	0.86 (0.74, 1.01)	0.98 (0.87, 1.11)	1.04 (0.85, 1.28)	1.01 (0.81, 1.26)	0.91 (0.74, 1.12)	0.89 (0.74, 1.08)	0.77 (0.63, 0.95)	1.30 (1.22, 1.38)	1.11 (0.70, 1.75)
50 to < 75th	0.75 (0.55, 1.02)	0.92 (0.78, 1.09)	1.05 (0.94, 1.18)	1.10 (0.93, 1.29)	0.89 (0.68, 1.17)	1.07 (0.96, 1.20)	0.89 (0.70, 1.20)	1.12 (0.68, 1.85)	1.24 (0.87, 1.78)
75 to < 95th	0.77 (0.62, 0.96)	0.85 (0.68, 1.07)	0.92 (0.69, 1.22)	1.11 (0.98, 1.25)	0.90 (0.71, 1.15)	1.06 (0.90, 1.24)	0.78 (0.60, 1.02)	1.08 (0.70, 1.66)	1.04 (0.55, 1.99)
≥ 95th	0.42 (0.30, 0.59)	0.86 (0.63, 1.16)	0.85 (0.68, 1.06)	1.15 (0.96, 1.38)	1.23 (0.85, 1.77)	1.28 (1.03, 1.59)	0.70 (0.42, 1.19)	0.49 (0.14, 1.73)	0.48 (0.32, 0.72)
per 1 ppm	0.56 (0.38, 0.81)	0.82 (0.56, 1.20)	0.73 (0.54, 1.01)	1.43 (1.18, 1.74)	1.27 (0.87, 1.86)	1.75 (1.50, 2.04)	0.37 (0.17, 0.80)	0.82 (0.22, 3.06)	0.61 (0.16, 2.29)
PM_{10}									
< 25th	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
25 to < 50th	1.13 (0.96, 1.33)	0.88 (0.77, 1.02)	0.84 (0.64, 1.11)	1.01 (0.98, 10.5)	1.10 (0.93, 1.30)	1.08 (0.92, 1.27)	0.83 (0.64, 1.06)	1.16 (0.84, 1.61)	0.77 (0.55, 1.07)
50 to < 75th	1.00 (0.92, 1.08)	0.95 (0.89, 1.02)	0.91 (0.83, 1.01)	0.88 (0.79, 0.98)	0.95 (0.80, 1.12)	0.89 (0.70, 1.12)	0.86 (0.70, 1.05)	0.86 (0.63, 1.19)	1.12 (0.76, 1.66)
75 to < 95th	1.00 (0.91, 1.09)	0.95 (0.84, 1.07)	0.80 (0.71, 0.90)	0.83 (0.70, 0.97)	0.88 (0.69, 1.11)	0.94 (0.75, 1.18)	0.79 (0.68, 0.93)	0.98 (0.71, 1.34)	0.93 (0.65, 1.31)
≥ 95th	0.92 (0.81, 1.04)	0.89 (0.64, 1.26)	1.03 (0.86, 1.24)	0.81 (0.67, 0.99)	0..75 (0.54, 1.03)	0.83 (0.71, 0.97)	1.36 (1.06, 1.75)	0.68 (0.38, 1.21)	0.90 (0.55, 1.47)
per 10 mg/m^3	0.94 (0.90, 0.98)	0.96 (0.89, 1.04)	0.95 (0.90, 1.00)	0.93 (0.85, 1.01)	0.92 (0.80, 1.05)	0.99 (0.87, 1.11)	0.96 (0.84, 1.09)	0.92 (0.81, 1.05)	0.96 (0.80, 1.15)
SO_2									
< 25th	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
25 to < 50th	1.00 (0.76, 1.33)	0.93 (0.80, 1.09)	0.97 (0.81, 1.16)	1.08 (0.93, 1.25)	1.22 (1.14, 1.32)	1.11 (0.95, 1.30)	0.88 (0.54, 1.45)	1.22 (0.74, 2.00)	0.78 (0.64, 0.96)
50 to < 75th	1.04 (0.77, 1.40)	1.16 (1.11, 1.22)	1.03 (0.81, 1.30)	1.10 (1.00, 1.20)	1.07 (1.04, 1.11)	1.05 (0.84, 1.31)	0.87 (0.55, 1.38)	1.23 (0.88, 1.84)	0.89 (0.61, 1.29)
75 to < 95th	1.15 (0.87, 1.52)	1.30 (1.20, 1.42)	1.20 (0.81, 1.78)	0.96 (0.84, 1.11)	1.03 (0.96, 1.10)	1.02 (0.83, 1.24)	0.75 (0.57, 0.98)	1.31 (0.84, 2.05)	0.90 (0.63, 1.28)
≥ 95th	1.11 (0.86, 1.44)	1.07 (0.63, 1.81)	1.22 (0.82, 1.80)	0.75 (0.64, 0.87)	0.84 (0.55, 1.27)	1.01 (0.67, 1.53)	1.27 (0.74, 2.16)	0.84 (0.53, 1.32)	0.89 (0.52, 1.52)
per 10 ppm	1.18 (1.12, 1.23)	1.18 (1.02, 1.35)	1.20 (1.06, 1.36)	0.91 (0.85, 0.98)	0.96 (0.80, 1.14)	0.95 (0.75, 1.20)	1.16 (0.74, 1.80)	1.14 (0.79, 1.63)	0.95 (0.74, 1.21)

inner-city residents where there might be higher ambient air levels of CO, to decrease the magnitude of the association between term LBW and CO. In fact, we found that the prevalence of term LBW among the infants evaluated was 3.7%, which was still slightly higher than the prevalence of term LBW in the general population (3.0%), suggesting that the above exclusions may have had negligible effects on the representativeness of the study subjects.

One assumption in this study is that maternal residence did not change during pregnancy. We do not have data on residential mobility for our study subjects to assess the extent to which this assumption is true. It is known that in the United States a proportion of pregnant mothers do change their residences between the time of conception and the time of birth of their offspring. For instance, a study of such maternal residential mobility in the State of Maryland in the early 1980s reported an overall rate of 20%, with higher rates among white women in the age group 20–24 years (*17*). A similar study in Santa Clara, California, reported a residential mobility rate of 25% (*18*). The impact of such residential mobility among our study subjects would be to misclassify exposures and more than likely weaken any associations between LBW and air pollutants.

Our classification of infants as term LBW was based on birth certificate data on birth weight and date of mother's LMP for estimating gestational age. Although such birth weight data are of reasonable quality, dates of LMP and gestational age estimates derived from them are less accurate and reliable (*19*). This uncertainty in gestational age of infants may have resulted in some misclassification of cases of term LBW as noncases and vice versa. Because the determination of a subject's case status was independent from exposure assessment, such misclassification was in all likelihood nondifferential and may have attenuated the relation between ambient air pollutants and term LBW.

Exposure assessment was based on data from stationary air pollution monitors that provided estimates of the concentrations in geographically defined regions and assumed that air pollution levels were homogeneously distributed within each region represented by a monitor. A study from Philadelphia showed that PM_{10} concentrations were relatively similar between monitoring stations located in various parts of the city, suggesting that PM_{10} distributions over a region are likely to be homogeneous (*20*). Results of a recent Dutch study indicating that fine particle data from stationary monitoring stations correlate well over time with corresponding individual personal monitoring data (*21*) provide some reassurance for the usefulness of stationary monitoring data on ambient air particles in exposure assessment.

In our study we estimated Spearman correlation coefficients for any two monitors within a city and found that these coefficients ranged from 0.43 to 0.91 for SO_2, 0.45 to 0.98 for PM_{10}, and 0.32 to 0.66 for CO. The range of PM_{10} coefficients is based on Boston, Hartford, and Springfield monitors only. Readings between monitors located within a city ranged from moderate to good for PM_{10} and SO_2, which suggests a low degree of heterogeneity in ambient concentrations within study areas. We also observed that monitor readings of CO did not correlate as well as those of the other two pollutants, suggesting the presence of large spatial variations in CO concentrations within an area.

These observations suggest that use of stationary monitoring data for assessing exposure to ambient air particles and SO_2 was reasonable. If misclassification occurred, such errors were probably nondifferential. For CO the correlation of stationary monitoring data with individual monitoring data may not be as strong. Because the main source of ambient CO is automobile exhaust (*22*), it is possible that the levels of CO recorded at stationary monitors may underestimate the levels to which pregnant women might be exposed at the street level or inside automobiles (*23*). If that is true, our exposure assessment approach may have resulted in nondifferential exposure misclassification and attenuation of the risk for term LBW in relation to CO levels.

Our study had several strengths. Our analyses controlled for most of the known determinants of LBW, including maternal age, race/ethnicity, years of education, marital status, gestational age, adequacy of prenatal care, maternal smoking and alcohol consumption in pregnancy, and infant's sex and birth order. Furthermore, by including infants from several cities, we decreased the probability of confounding by unmeasured risk factors that covaried with area of maternal residence (*24*). By focusing on term LBW, we were able to examine the effect of air pollutants on fetal growth independent from the effects of prematurity.

We found an increased risk for term LBW in relation to increasing levels of CO > 1.46 ppm during the third trimester. This result is consistent with findings in previous studies (*3,7*). Alderman et al. reported a nonsignificant increased risk for LBW at third trimester average levels of CO ≥ 3 ppm (*7*), while Ritz et al. reported effects on fetal growth at average levels of CO > 5.5 ppm (*3*). Although these results suggest a threshold effect for the effects of CO on fetal growth, the possibility of attenuation of effects due to exposure misclassification at lower exposure levels cannot be excluded.

We also observed an association between exposure to SO_2 and risk for term LBW, and other studies have reported similar effects. A study conducted in China reported an association between the risk for term LBW and third trimester exposures to SO_2, and another study reported a small increase in risk in areas with increased exposures to SO_2 (*1,5*). Further studies are needed to elucidate the nature of this association.

In contrast to previous studies (*2–5*), we found no consistent evidence of an association between LBW and PM_{10}. A mechanism postulated to mediate the association between LBW and PM_{10} is that PM_{10} carries PAHs, which might have adverse effects on fetal growth (*11,12*). If this is true, one possible explanation for our failing to detect an association with PM_{10} is that there might be a threshold effect, but the ambient levels of PM_{10} in our study area were below the threshold level. Another possibility is that exposure misclassification may have biased any real associations towards the null.

When we stratified the analysis by maternal race we saw that the association of CO with term LBW appeared to be limited to African–American infants, while the effects of SO_2 appeared to be more consistent in white infants. We do not know the reasons for the racial/ethnic difference in these associations, but possibilities include differences in other factors or exposures that may increase the susceptibility to term LBW, such as socioeconomic status, prepregnancy weight, amount of cigarette smoking, and level of exposure misclassification. For instance, if compared to African Americans, whites and Hispanics tend to live further away from the monitor stations, their exposures to CO may have been misclassified to a greater degree and thereby decreased the likelihood of detecting any associations. In addition, further study is warranted to elucidate the reasons for the observed heterogeneity in effects by race/ethnicity.

Our findings suggest that air pollution may be associated with an increased risk of term LBW among infants of women residing in northeastern cities of the United States. Further work is warranted to corroborate these findings of potential public health importance. The prevalence of exposure to the kind of ambient air observed in this study among pregnant women in urban environments may be appreciable. Even a small increase in the risk for LBW from such levels could translate into a substantial number of affected infants with an increased risk for mortality and for developing other serious health problems, including developmental disabilities and chronic respiratory conditions (*25,26*).

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